Stamping Simulation Model
for Titanium Sheet

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Table of contents

1) Introduction
   Examples of stamping application
2) Considerable Condition
   on titanium stamping simulation
3) Development of stamping
   simulation model
4) Conclusion
Stamping application for I.T. body parts

- **Stamping requirement at customers**
  1) Dimensional precision forming
  2) Difficult forming

Application areas are widening & increasing!
However, there are some difficulties in titanium stamping
Recent example of titanium stamping products

Sony Network walkman NW-MS70D  2003/02
Recent example of titanium stamping products

SONY Linear PCM recorder PCM-D1 2005/11
Recent example of titanium stamping parts

Difficult forming: Increasing stamping stages

Stage #1 ➔ #2 ➔ #3 ➔ #4
Recent example of titanium stamping parts

Examples of precision forming

They used Nippon Steel material

Sharp corner

Dents portion
Considerable condition on titanium stamping simulation

1. Mechanical property
2. Lubrication
3. Die design (Process design)
1. Mechanical property

Plasticity anisotropy
Anisotropic work-hardening of pure titanium
Experiment equipment of yield-surface measurement

- Laser CCD for Curvature, Radius measurement
- CCD Camera for Longitudinal Strain measurement
- Axial Force
- Internal Pressure
Stress ratio control system

Main CPU
VXI-bus system

Internal pressure \( p \)

\[
\frac{\sigma_\phi}{R_p} + \frac{\sigma_\theta}{R_\theta} = \frac{p}{t} \left( 1 - \frac{t}{2R_p} \right) \left( 1 - \frac{t}{2R_\phi} \right) \left( 1 - \frac{t}{2R_\theta} \right)
\]

\[
2\pi\sigma_\phi R_\phi t = \pi p \left( R_\phi - \frac{t}{2} \right)^2 + W
\]

Stress ratio \( \alpha = \sigma_\phi / \sigma_\theta \)

Cylinder Load control

\( W_r \) Cylinder Load

Pipe Profile and strain

Pipe curvature and strain
- Longitudinal radius \( R_\phi \)
- Circumferential radius \( R_\theta \)
- Circumferential strain \( \varepsilon_\theta \)

3 Laser displacement (CCD) sensor

Positioning revision

Pipe strain
- Longitudinal strain \( \varepsilon_\phi \)

CCD camera

Software digital servo
DSP TM320 40MHz

PA-RISC PA-7200 132MHz
DSP : TM320 40MHz x 3
Yield surface of titanium ($r_0 = 1.7$ $r_{45} = 4.3$ $r_{90} = 4.8$)
2. Lubrication Conditions

- Lubricating method
  (reducing friction)

- Life of die
  (preventing crack initiation, seizure, galling)
Effect of lubrication on forming height

No lubrication
Height=9mm

Normal lubrication
Height=11mm

Good lubrication
Height=14mm

Erichsen cup test:
Sheet thickness= 0.5mm
3. Die design (Process design)

Conner radius, Clearance, Blank Hold Force (BHF), etc

“Try and Error” increases costs
Effect of clearance on shock-line

a) Clearance: small

b) Clearance: large
Development of stamping simulation model for titanium sheet

- Deformation behavior of titanium
  1) Large plastic anisotropy
  2) Anisotropic work-hardening
     (Steel follows isotropic hardening rule)

- Frictional resistance
  Effect of friction coefficient

- Full 3D FEM simulation
  Consideration of thickness direction stress

Measuring yield-surface
Constitutive equation
3D elastic-plastic FEM simulation
Development of stamping simulation model for titanium sheet

Conventional model
- Plane stress model
  \[ \sigma_z = 0 \text{ and } \tau_{yz} = 0 \text{ and } \tau_{yz} = 0 \]
anisotropic work hardening not considered

Development model
- Full 3-dimensional model
  \[ a_1 (\sigma_y - \sigma_z)^2 + a_2 (\sigma_z - \sigma_x)^2 + a_3 (\sigma_x - \sigma_y)^2 \]
  \[ + a_4 \tau_{yz}^2 + a_5 \tau_{yz}^2 + a_6 \tau_{xy}^2 = \bar{\sigma}^2 \]
anisotropic work hardening considered
Thickness direction stress considered for ironing
Meshing of 3D FEM simulation model

5 divisions in thickness direction

5 divisions in thickness direction

t=0.5mm
An example of stamping titanium

Experiment

3D-FEM simulation

Canning

Shock line

Square-shell deep drawing
Deformation of titanium sheet (Animation)
Thickness direction strain distribution (Animation)

LE, LE33
(Ave. Crit.: 75%)

Step: Step-1  Frame: 30
Forming-load simulation during stamping

- Stamping load (kN) vs. Forming height (mm)
- Measure (blue line)
- Calculation (red line)
Flange-profile simulation of titanium sheet

H=0mm 10mm 20mm 30mm

Calculation

Experiment
3-dimensional shape measurement
Thickness distribution of square deep-drawing (H=30mm)

Calculation Experiment

- B.H.F = 10 kN
- $\mu = 0.03$

![Graph showing thickness distribution](image-url)
The application and solution of titanium stamping

Part design

Process design

Forming validation

Simulation model

Predict and solve difficulties:
- Material mechanical properties
- Lubrication
- Die design

Recommend:
- Die-design
- Stamping condition
- Materials
Coming soon

- Digital camera body parts

Photokina world imaging in Köln
26.09.2006 Debut
In the FEM simulation, both anisotropy of plasticity and anisotropic work hardening model were adopted for high precision calculation of titanium stamping.

- Thickness strain distribution and deformation of blank (material plastic flow from flange) caused by stamping were consistently calculated using the FEM model.
- The results were in good agreement with behaviors of square-shell deep drawing of pure titanium sheets observed in experiments.